Fritz Laboratory Reports | Civil and Environmental Engineering

1974

Effects of input parameter variation on sedimentation in reservoirs, Supplement to "Bed Load Deposition and Delta Formation: A Mathematical Model" by Oner Yucel and Walter H. Graf, December 1973; October 1974

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Reservior Sedimentation

EFFECTS OF INPUT PARAMETER VARIATION ON SEDIMENTATION IN RESERVOIRS

Supplement to

Bed Load Deposition and Delta Formation:
A Mathematical Model
by Oner Yucel and Walter H. Graf
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Fritz Engineering Laboratory Report No. 384.2

I. Introduction

This report contains material which relates directly to the report

> "Bed Load Deposition and Delta Formation: A Mathematical Model", by Oner Yucel and Walter H. Graf, December 1973, Fritz Engineering Laboratory Report No. 384.1.

It is assumed that the reader of this report is entirely familiar with the contents of the above mentioned report.

The material in the following sections of this report consists of a discussion of the computer program in general, with some important comments that were not included in the initial report. One section is devoted to some computational details that require emphasis. Unfortunately, the computer program has limitations which prohibit normal execution under certain input conditions. These problems are a subject of another portion of this report. Finally, the results of varying the input parameters are discussed and some generalities concerning delta formation are stated.

II. General Comments on the Program and the Initial Report

A. Modifications

Since the completion of the initial report, the computer program has been modified to include a fourth bed load equation. This equation, which is the result of work done by Acaroglu and Graf, can be expressed by:

$$g_s = \frac{10.39q}{vD} \frac{\sqrt{(S_s-1)d_{50}^3 g}}{\left[\frac{(S_s-1)d_{50}}{SD}\right]^{2.52}}.$$

To utilize this equation during the program execution, it is necessary to set the input parameter NEQ equal to 4. However, using this equation produces either abnormal termination of execution or unsatisfactory results. These aspects will be discussed later.

A fifth bed load equation has been partially written into the computer program. This last approach is the result of studies conducted by Laursen. All of the necessary changes to the program have been made, with the exception of the inclusion of the computational statements. A review of the present program reveals that statements need to be written for only the subroutine DPBL. The remaining subroutines that refer to the Laursen equation already have the necessary statements. These existing equations refer almost entirely to the output formats for both the printer and the plotter. The Laursen solution is identified by setting NEQ equal to 5.

B. Conditions under which the Equations are Applicable

The research conditions preceeding the development of the

Schoklitsch, the Meyer-Peter Muller, and the Einstein-42 bed load equations varied significantly. The studies involved different sediment, stream, and reservoir characteristics. Table 1 contains the ranges of particle diameters for which the equations are applicable.

Table 1

Particle Size for Which the Bed Load Equations are Applicable

Equation	Particle Diameter (mm)
Schoklitsch-Hjulstrom	>6
Meyer-Peter Muller	5 to 28
Einstein-42	0.8 to 28

The bed load rates predicted by the three equations under a given set of parameters differ significantly, often by an order of magnitude. A comparison was made of how the equations react to varying parameters. The control set of parameters, or the base from which the parameters were varied, was the following:

Flow rate, $q = 2.0\ m^3/sec/m$
Manning's $n = 0.025$
Bed slope, $S_b = 0.0001$
Particle size, $d_{50} = 0.010\ m$

Figures 1, 2, 3 and 4 show the bed load rate plotted against the flow rate, bed slope, particle size, and Manning roughness, respectively. These plots will be used to help explain the delta formations that were predicted by the various sets of parameters.

The research work that preceeded the compilation of the initial report was concerned primarily with small particle sizes. The discussions and results are based on computer runs with sediment diameters of 0.5, 1.0, and 2.0 mm. Table 1 shows that Einstein's equation is the only one that is clearly applicable in this range.

When reviewing the results of the initial report, it should be remembered that the Schoklitsch and Meyer-Peter Muller equations were utilized with sediment sizes that are outside their recognized range.

III. Program Details of Rate

A. Slope

The initial report mentions the fact that the bed load equations were written for uniform flow conditions and thus the three slope terms (i.e., river bed, water surface, and energy slopes) are equal. In the reservoir problem, the slopes are not equal, and it is necessary to choose a slope value to insert into the equations. The authors then state (p. 16) that an effective channel slope was selected. This slope is defined as an average of the bottom and energy slopes.

An examination of the computer program reveals that apparently, only the energy slope is used in the calculations. A specific investigation was conducted to determine exactly which slope values are being employed. The following eight steps demonstrate that the value of the slope term used in the bed load equations is definitely the energy slope.

The array containing the values of the energy slope (SE) is defined and used in the manner shown below.

1. SEDRES calls WPROF with SE as a parameter.
2. WPROF calls SLOPE with SE1 as a parameter.
3. SLOPE calculates the energy slope by using the Manning equation and returns the value to WPROF in SE1.
4. WPROF calls INDXV with SE(NS) as a parameter.
5. INDXV equates SE(NS) with SE1, SE1 being transferred in COMMON/REACH1, and execution returns to WPROF.
6. WPROF returns to SEDRES with SE defined as the energy slope.
7. SEDRES calls DPBL with SE as a parameter.
8. DPBL equates STEM with SE(NB) and uses STEM in the bed load equations (e.g., DPBL.92 and DPBL.100).

Although the descrepancy between the report and the program may be disconcerting, this investigation started because it was believed that using just the energy slope in the calculations would model the phenomena more accurately than by using an average of the two slope terms.

B. Delta Depth

The computer program treats the changes in the reservoir bottom profile due to sedimentation, in the following manner. The bed load equations predict either the weight or the volume of sediment that is transported by the river. By calculating the bed load capacity at both ends of a reach, and by subtracting one from the other, the amount of sediment deposited along that reach is obtained. The program then divides the volume of sediment by the length of the reach and arrives at the depth increment in the reach. This last step assumes that the volume of sediment is laid down as a solid mass without any pore spaces. Such an assumption is quite unrealistic. Initially sediment deposits have a high porosity and, with time, the succeeding layers of sediment compress the bottom layers and thus decrease the porosity of the latter. It appears that at no time does the porosity reach zero.

A computer run was made that assumed a constant porosity of the sediment deposits and adjusted the depth increments accordingly. The results were that the shape and location of the delta remained the same as when porosity was ignored. Naturally, the rate of formation was faster and more computer time was required because the back water profile was calculated more frequently.

This subject of porosity and the effect it has on the rate of delta formation is quite important. In a more sophisticated model, this factor should be included.

C. Erosion

In nature, the formation of a reservoir is a very unsteady process. At different times, the stream may be either depositing or eroding material. This aspect was not incorporated into the present program. Because it is assumed that the flow in the river is constant and at its bed load capacity, erosion was not expected to occur. In fact, in subroutine DPBL (card 134), if erosion is predicted over a certain reach, the change in bed load over that reach is set equal to zero. The assumptions justify this approach. Under these conditions, any prediction of erosion would probably be due to round-off errors.

Two computer runs were made to see if erosion occurs under the prescribed assumptions. The program was altered slightly so that the calculations would not be affected, but so that a message would be printed out every time erosion was encountered. In both cases, erosion did not occur. The second case had an additional different feature. The flow rate was gradually increased and then decreased to its initial value. Even under these conditions there was no evidence of erosion.

Future studies should recognize the fact that the streams are not always transporting their full bed load capacity and thus, may cause erosion as they enter the delta area. With this feature incorporated into the model, more realistic comparisons with existing reservoir systems could be made.

D. Output

The final point to be made in this section concerns a small detail in the computer program's printed output. After the bed load deposition calculations are printed in a table, there is a brief section that concerns the amount of sediment deposited. In this section, the amounts of sediment are expressed in either cubic meters per month or metric tons per month (p. 82). Using the units of month is correct only when the parameter FAC, which is the length of the sedimentation period in seconds, is set equal to the number of seconds in a month.

Although in the initial report (p. 19) it is stated that a thirty-day sedimentation period was selected, the Appendix reveals that the value of FAC was set equal to the number of seconds in a day (p. 78). However, this slight error does not affect the results of the computations.

IV. Technical Problems with the Computer Program

The introduction of this paper refers to the program limitations that prevent normal execution under certain input conditions. The fact that results cannot be obtained for these parameters is not the only consequence of this situation. The types of errors that the computer diagnoses are indicative of some very basic problems with the program. Although these problems have not been solved, they have been identified.

A. Subroutine REACH

1. Back Water Profile

The computer program is written in such a manner that it recomputes the reservoir back water profile after a significant amount of sediment has accumulated. The computation of this back water curve is straightforward when the reservoir bottom is fairly smooth. Unfortunately, the faces of some deltas have very abrupt changes in slope and it appears that subroutine REACH, in which the curve is calculated, cannot handle these conditions. The problems develop when a rapid delta formation rate is predicted and the face approaches a vertical line. The use of the Acaroglo-Graf bed load equation has frequently resulted in abnormal termination of execution. With large diameter particles (10 mm) the Meyer-Peter Muller equation was unsuccessful, also.

The computer identifies these problems by specifying that the reason for termination is either a mode 2 or a mode 4 error. In both cases the address of the error indicates that it occurs in subroutine REACH. A close investigation of a computer run, with a certain set of input parameters, revealed that the back water profile calculations predicted a positive depth increment in one section, as they worked their way upstream. The program then proceeded to reduce the increment, by trial and error, until it was on the order of 10^{-14} meters. In a different run, still using the Acarogol-Graf equation, a positive depth increment was again predicted, but this time the use of excessive computer time stopped the calculations.

To correct these conditions, the back water profile statements should be modified to handle abrupt changes in the reservoir bottom surface. An efficient and accurate method for determining the back water curve is essential to the computer program.

2. Tolerance Factor, EPSMIN

One of the several ways to increase the accuracy of the calculations is by specifying a small value for the input parameter EPSMIN. In the initial report, and for a majority of the work done for this report, a value of 0.10 was used for EPSMIN. A study was made to determine the effect of smaller values of EPSMIN on the program execution.

In rubroutine REACH a check is made to determine if the back water profile calculations have reached the river section. To do this, the program determines if the section bed slope is within a certain percentage of the river bed slope. Then a check is made on the percent difference between the section bed slope and the section energy slope. If both checks are less than or equal to EPSMIN, then it is assumed that the river has been reached. If this is not the case, then parameters for a new reach are calculated. If both checks are within EPSMIN, then the depth at the upstream end of the reach is set equal to the normal depth, and all the slopes (energy, water and bed) are set equal to the initial river bed slope.

Several results occur when the value of EPSMIN is varied. In order to evaluate this, the program was run using the Meyer-Peter Muller equation, and EPSMIN values of 0.05, 0.03 and 0.025. In general, all the equations predict a sudden decrease in depth at the upstream end of the last reach when a value of 0.05 is used. This is due to the fact that the depth at this point is not calculated. Instead, it is automatically set equal to the normal depth. When an EPSMIN value of 0.025 was used the program required excessive computer time. The nature of the program is such that if the river is not reached in the number of sections that are dimensioned, then the array length is increased and the profile is recalculated. By specifying a small tolerance, the array length must be lengthened several times in each cycle. Under these input conditions, an EPSMIN value of 0.025 is too small to be practical. It is interesting to note that for the cases studied, a value of 0.03, which is only slightly larger than the preceding value, is practical from a computer time viewpoint, and it is small enough to eliminate the large decrease in depth at the last section.

It appears that, by using an EPSMIN value of 0.10, the results may be less accurate, but it is possible to obtain a complete and efficient computer execution for the three bed load equations.

B. Peculiarities of the Plots

There are often irregularities in the computer program plots. Because the program is not forced into calculating elevations for a specified length of the channel, the lines do not extend upstream to the same point. Due to the nature of the program the calculations for a certain water profile cease when the flow parameters are close enough to those representing normal flow. One might expect that each succeeding back water profile would extend upstream further than the ones before it. In general, this is not true. There are two reasons that may account for this behavior. First, the calculations are based on meeting a tolerance, and this fact alone could be responsible for the varying profile length. Second, the last point to be plotted (i.e., the furthest upstream) is not the point of normal flow, but rather the point just before the river reaches normal flow. Since the reaches may vary in length, so may the location of this last point.

The above discussion appears to be centered around a rather insignificant point. However, the problems become quite serious when the program is run using the Acaroglo-Graf equation. Both the bottom and water surface profile lines stop right at the front edge of the delta. Apparently the program has selected a reach of such a significant length that the next section is at normal depth. Once this occurs for one profile, the succeeding ones are not reliable because the sediment deposition calculations have been based on an incorrect bottom profile. It may be possible to correct this situation by restricting the reach lengths in the delta area.

This problem, like those in the immediately preceding paragraphs, stems from computational difficulties in subroutine REACH. Once this subroutine can accommodate all of the possible bottom formations, these problems should be eliminated.

V. Effects of Parameter Variation and Comparison of the Three Equations

Several sets of computer runs were made in which one input parameter was varied from run to run and the remaining ones were held constant. The reservoir and stream characteristics under investigation were the Manning roughness coefficient, n, the sediment size, D_{50}, and the length of the sediment period. The parameters that remained constant at all times were the discharge per unit width, q, and the initial bottom slope of the reservoir and the stream, s_b.

A. Manning Roughness, n

Computer runs were made with n values of 0.025 and 0.035 and sediment sizes of 0.5mm and 10mm. It should be noted that changing the roughness affects the solution in several ways. An increase in roughness, while maintaining a constant bottom slope, flow rate and sediment size, has the effect of increasing the normal depth and of decreasing the velocity. Figure 4 illustrates how the bed load capacity, as predicted by the three equations, varies with different values of Manning's n.

Figures 5, 6 and 7 show the delta formations for the Schoklitsch-Hjulstrom, Meyer-Peter Muller and Einstein-42 bed load equations with a sediment size of 0.5mm. In all three cases, the higher n value of 0.035 causes the delta to form closer to the dam. In two of the figures, Schoklitsch-Hjulstrom (Fig. 5) and Einstein-42 (Fig. 7), the lower n value is responsible for forming a steeper-faced delta, whereas the opposite is true for the Meyer-Peter Muller figure (Fig. 6).

A similar study was made using a sediment size of 10 mm which is within the alleged applicable range of all three equations. The results are shown in Figs. 10 and 11 which correspond to the Schoklitsch-Hjulstrom and the Einstein-42 bed load equations. Unfortunately, the computer program was not successful with this sediment size using the Meyer-Peter Muller equation. The qualitative results are the same as the ones discussed in the preceding paragraph. A comparison of the bed load rates shown in Fig. 4 and the relative delta sizes in Figs. 10 and 11 illustrate that as the bed load capacity increases so does the depth of the delta.

B. Sediment Size

Computer runs were made to determine the affect on delta formation of the 1 and 10 mm sediment sizes. Figure 3 shows that the bed load capacity, as predicted by both the Schoklitsch-Hjulstrom and the Einstein-42 equations, decreases significantly with this change in sediment size. Figure 14 and 15 show that in both cases the deltas formed with the 10 mm particles are smaller and further upstream than 1 mm particle deltas. These two generalities are to be expected since the bed load capacity is smaller for the 10 mm sediment size and since larger particles settle out faster and therefore further upstream than smaller particles. These observations differ somewhat from those made in the initial report. The author noted that under the conditions studied, the Schoklitsch-Hjulstrom delta formation rate did not depend much on sediment size. It should be emphasized that this generality applies only under certain conditions.

C. Sediment Period

Computer runs were made to observe the effect of the sediment period length on the delta formation. The Meyer-Peter Muller and the Einstein equations were selected, because, for the flow parameters selected (D_{50} = 0.5 mm and n = 0.025), the former predicts a rapid delta formation while the latter predicts a slow one. Both programs were run for sediment periods of six hours and one day.

The results of the Meyer-Peter Muller runs show that, for the six-hour sediment period, a smoother, more shallow and slightly larger delta than that for the 24-hour period delta. This is because the nature of the program is to recompute the water surface profile whenever the sedimentation exceeds 2% of the depth from the previous water profile calculations. Therefore, if the rate of sedimentation is rapid, then the specified period should be small. This precaution ensures a sufficient frequency of back water calculations. Another result of reducing the sediment period is a 30% reduction of the sedimentation time span for a given length of computer time.

The results of the Einstein-42 equation runs show that the delta formations are almost identical. This is to be expected because the computer run with a 24-hour period had several deposition cycles between back water calculations. This means that the 24-hour period was sufficiently small and any further reduction would have no significant effect.

D. Comparison of Equations

A significant portion of this study is the comparison of the delta formations predicted by the three equations under the same input parameters. Figures 8 and 9 show the superimposed deltas for a sediment size of 0.5 mm and a Manning roughness of 0.025 and 0.035, respectively. The shapes and sizes of the deltas, relative to each other, are the same in the two figures. Under these input conditions the Meyer-Peter Muller equation predicts a delta formation rate that is over five times as fast as the Schoklitsch-Hjulstrom rate and over ten times as fast as the Einstein-42 rate. The observation differs significantly from that made in the initial report which, under different conditions, states that the formation rates predicted by the Meyer-Peter Muller and the Einstein-42 equations were similar and that they both were twenty times as fast as the Schoklitsch-Hjulstrom rate.

A similar study was made using a sediment size of 10 mm. The results shown in Figs. 12 and 13 illustrate that the delta formation rate predicted by the Einstein-42 is approximately five times faster than the one predicted by the Schoklitsch-Hjulstrom equation. Although the deltas are located in the same position, the Einstein-42 equation also predicts the formation of a steeper face sooner than the Schoklitsch-Hjulstrom equation.

The differences in delta formation rate can be attributed to the extremely different bed load capacities of the three equations. Figures 1, 2, 3 and 4 show that the equations react differently and to varying degrees when various parameters are altered.

VI. Summary, Conclusion, Recommendations

This investigation has observed the effects of varying the reservoir and stream input parameters for a reservoir sedimentation mathematical model. During the course of this study, certain computer program difficulties arose and an attempt was made to diagnose these problems. Also included are several figures of the deltas formed under various sets of reservoir characteristics which allow a visual comparison of the differences among the three bed load equations included in this study.

The major conclusion of this study is that the technical problems that were discussed earlier in this report need to be corrected before the results become completely satisfactory. There are several problems that occur with the calculation of the back water profile curves which may affect all of the results.

It is apparent that generalities should not be made. Conclusions of the initial report have been shown to be invalid for the conditions under which the program was run in this investigation.

The assumptions that were made when the program was written (see initial report) impose strict limitations on the application of the results. Future work should concern the incorporation of the following features into the model.

1. The effect of the river increasing in width as well as depth as it enters a reservoir.
2. The variation in bed load and the change in flow rate of the river.
3. The mechanism of erosion.
4. The elimination of a vertical face delta which may now be predicted if the formation rate is fast.

5. The gradation of sediment and a deposition mechanism that accounts for porosity.

Until all of these recommendations are included in the computer program, the results will be only qualitative. The results to date indicate that the general approach to the problem of sedimentation is reasonable, but the model will only be as good as the bed load equation that it uses.

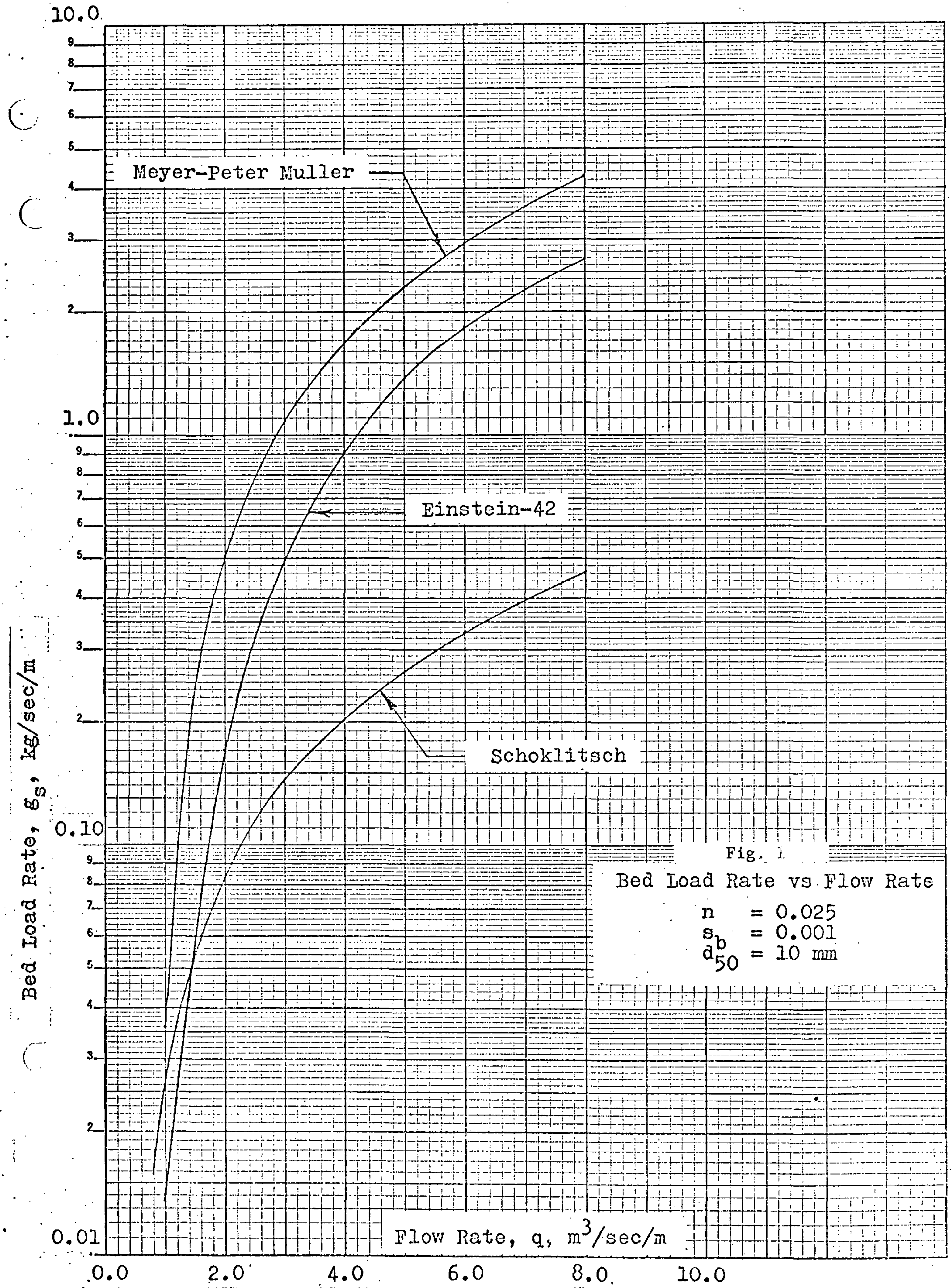

Fig. 1

Bed Load Rate vs Flow Rate

$n = 0.025$
$s_b = 0.001$
$d_{50} = 10$ mm

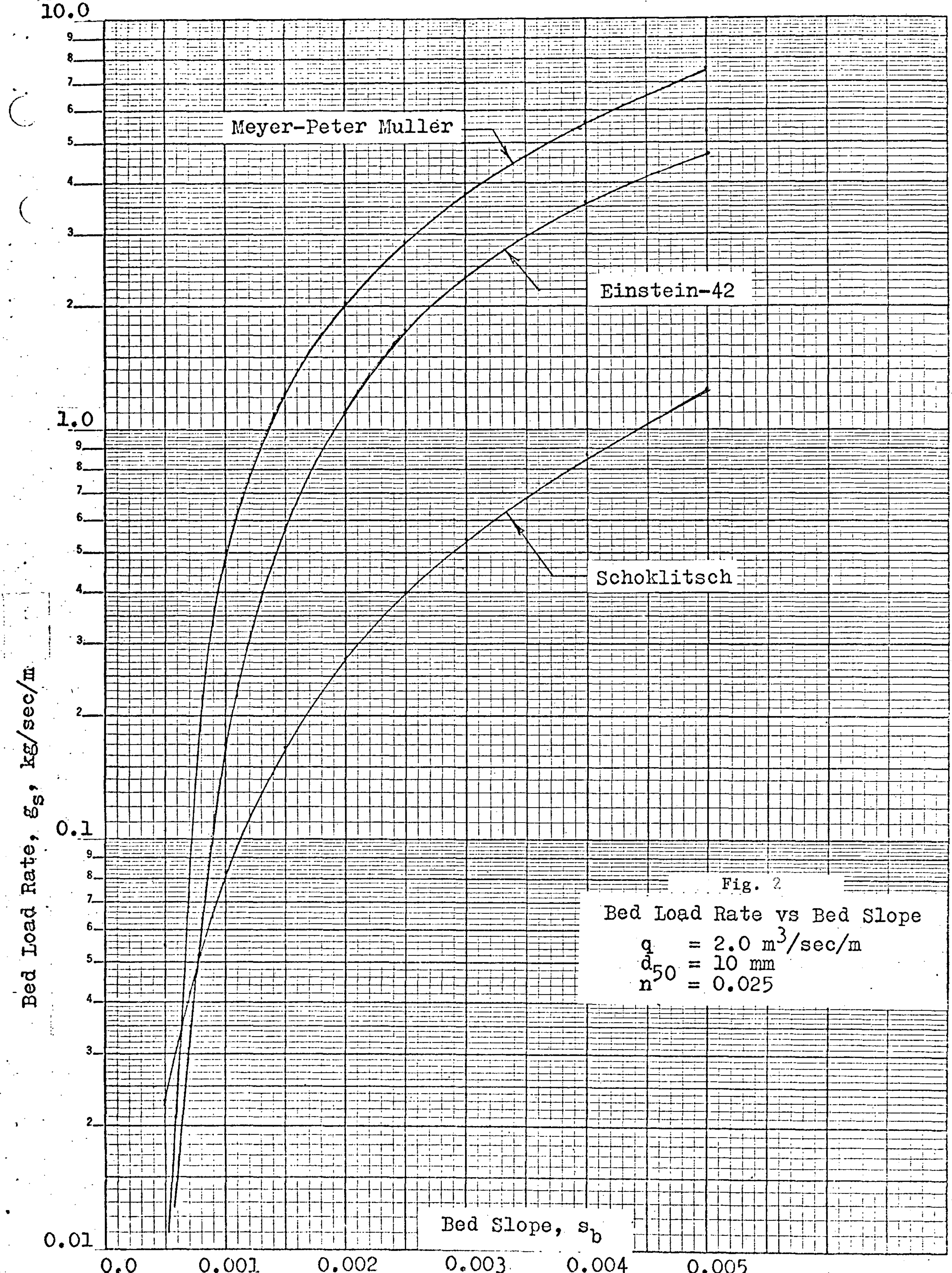

Fig. 2

Bed Load Rate vs Bed Slope

$q = 2.0\ m^3/sec/m$

$d_{50} = 10$ mm

$n = 0.025$

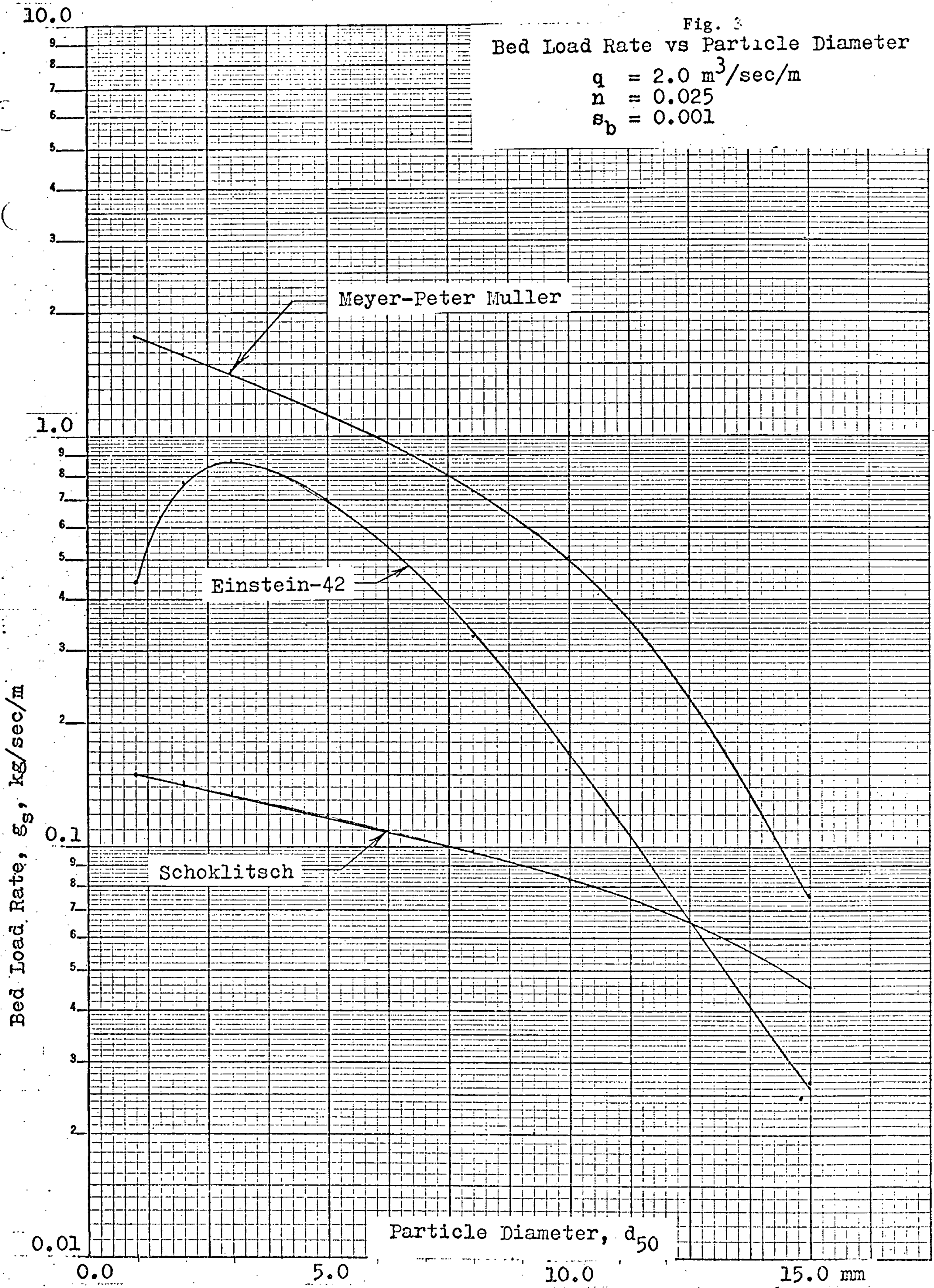
Fig. 3
Bed Load Rate vs Particle Diameter
q = 2.0 m3/sec/m
n = 0.025
sb = 0.001
Meyer-Peter Muller
Einstein-42
Schoklitsch
Bed Load Rate, gs, kg/sec/m
Particle Diameter, d50
10.0
1.0
0.1
0.01
0.0
5.0
10.0
15.0 mm

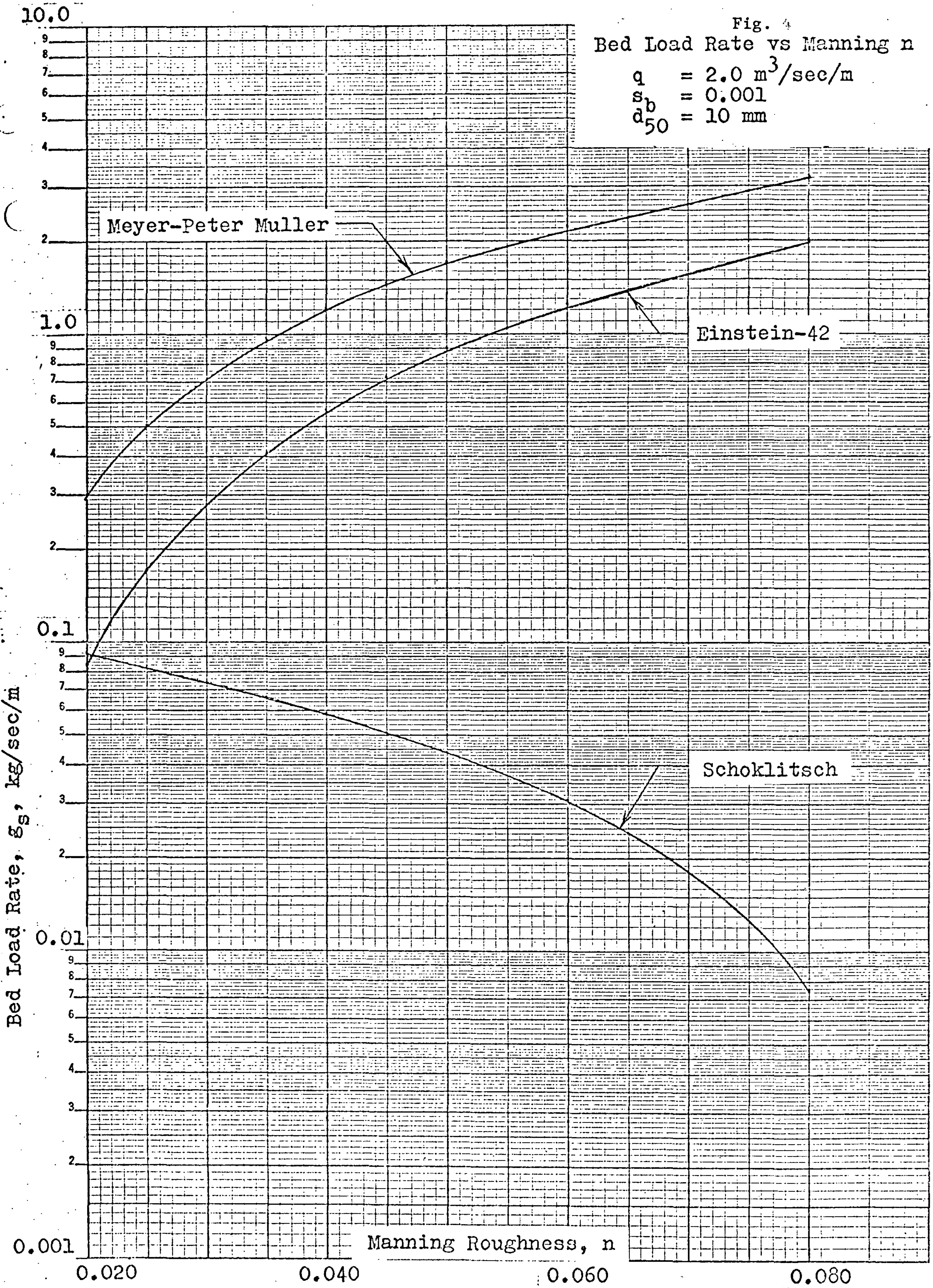
Fig. 4
Bed Load Rate vs Manning n
q = 2.0 m^3/sec/m
s_b = 0.001
d_50 = 10 mm
Meyer-Peter Muller
Einstein-42
Schoklitsch
Bed Load Rate, g_s, kg/sec/m
Manning Roughness, n
10.0
1.0
0.1
0.01
0.001
0.020
0.040
0.060
0.080

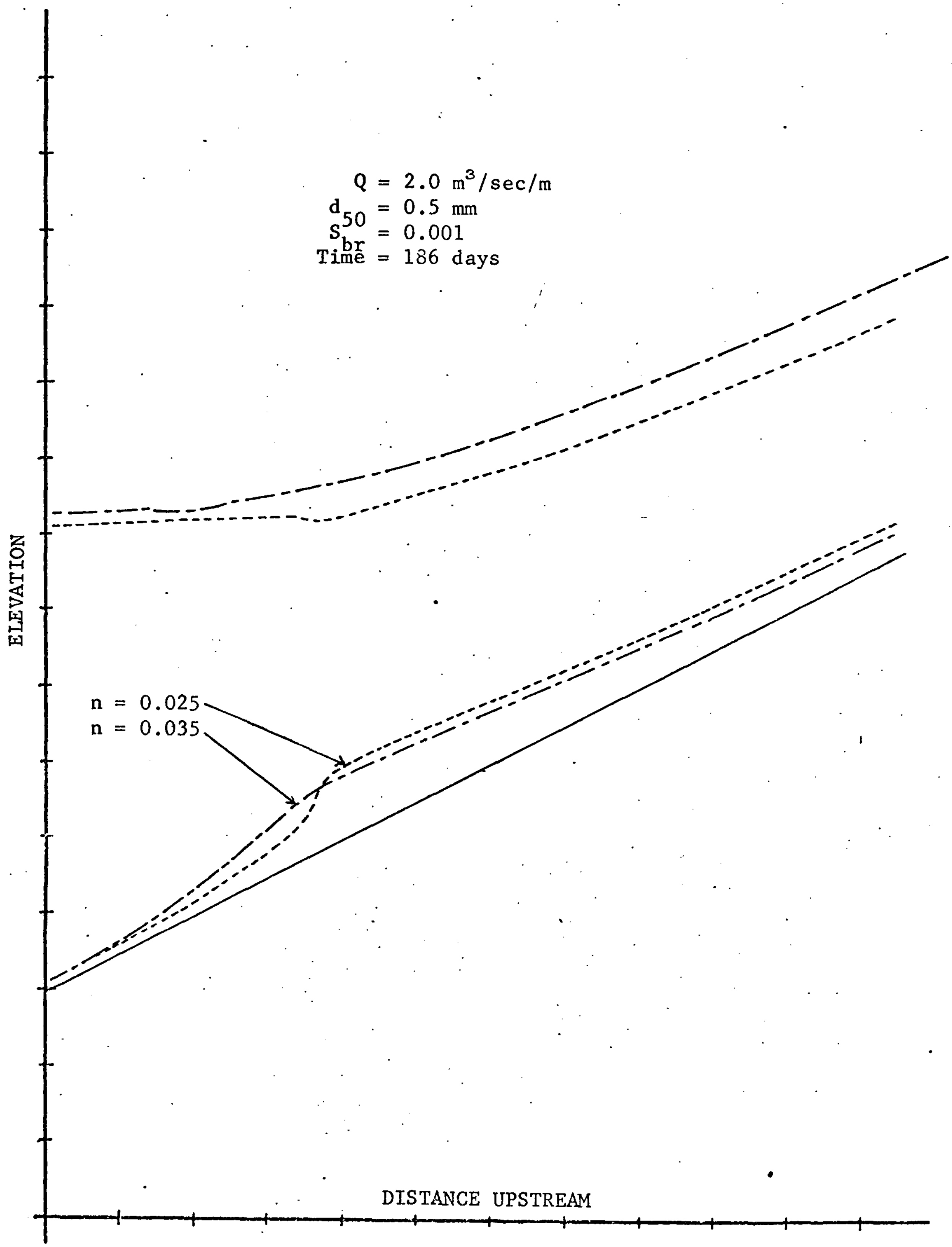

Fig. [illegible] Effect of Manning n, Modified Schoklitsch Equation

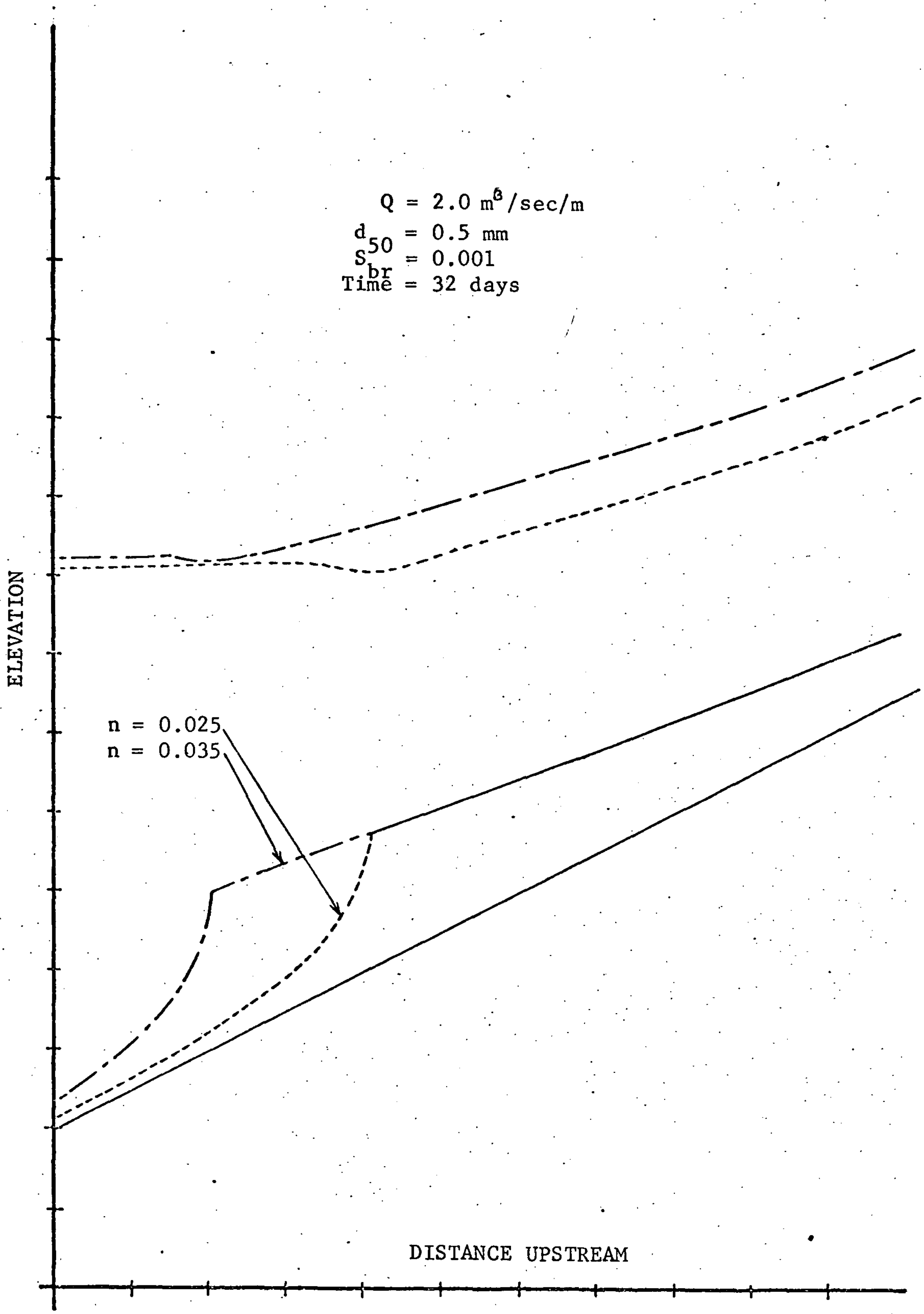

Fig. 6 Effect of Manning n, Meyer-Peter Muller Equation

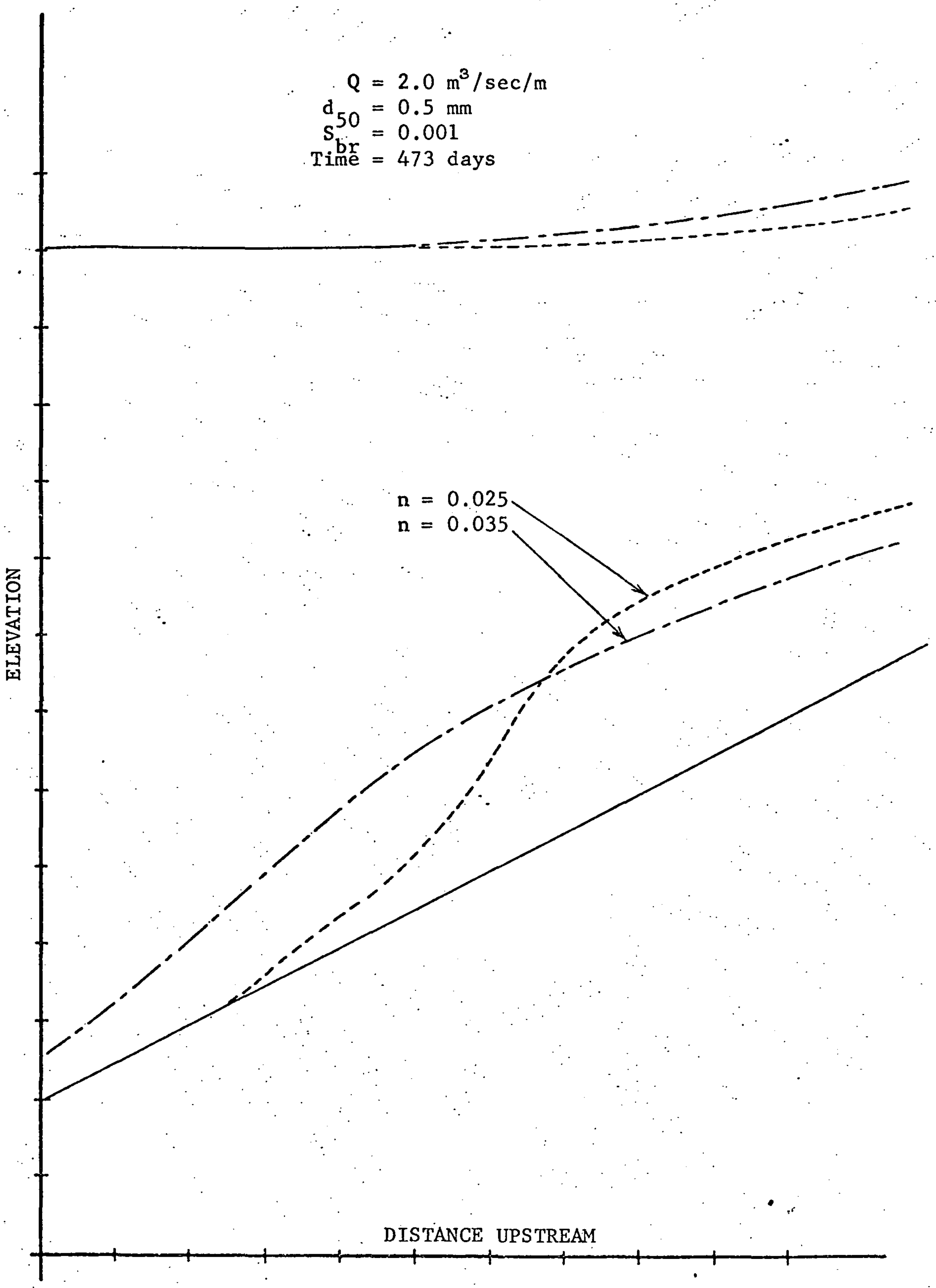

Fig. 7 Effect of Manning n, Einstein-1942 Equation

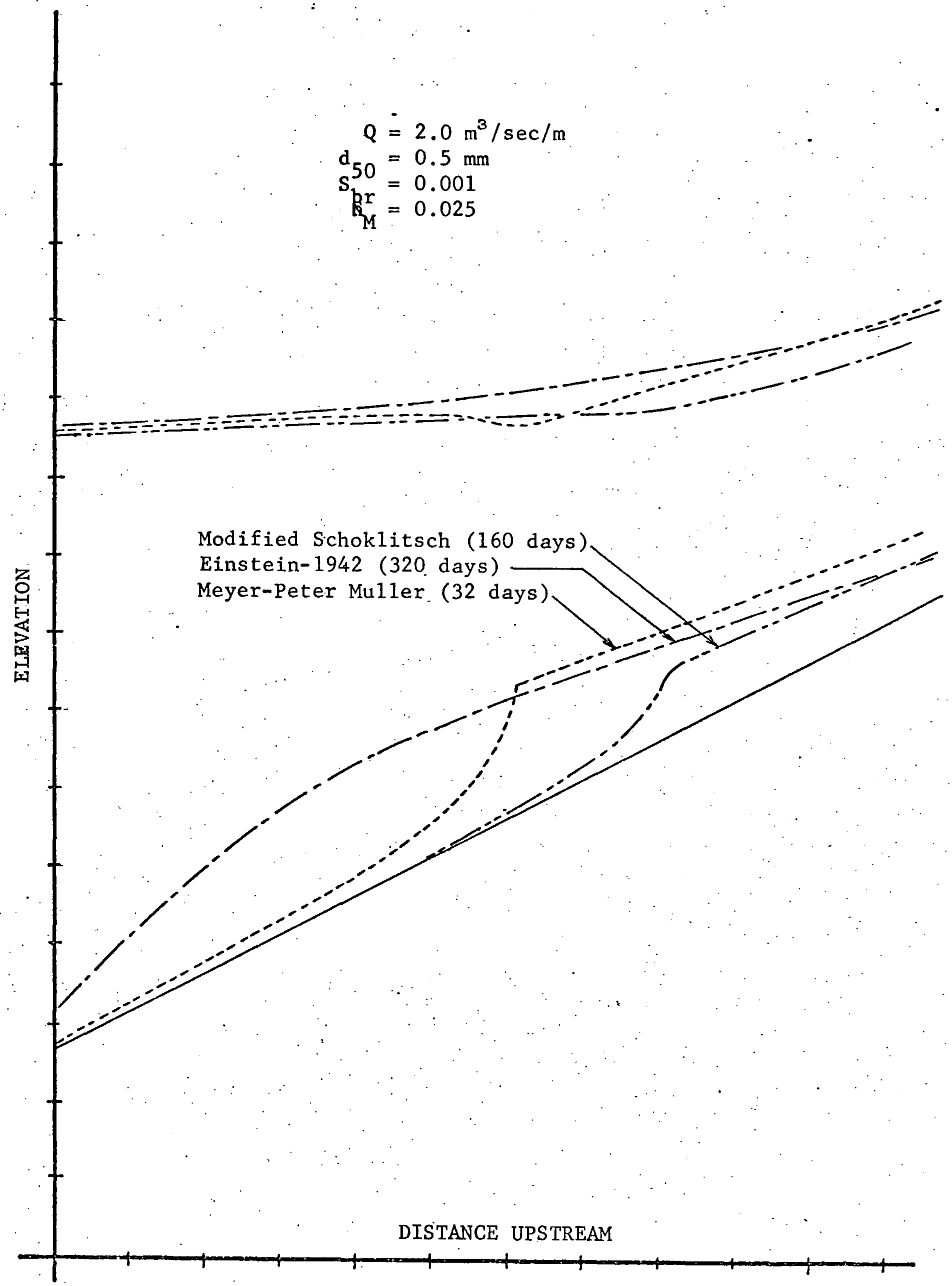

Fig. Comparison of Three Bed Load Equations

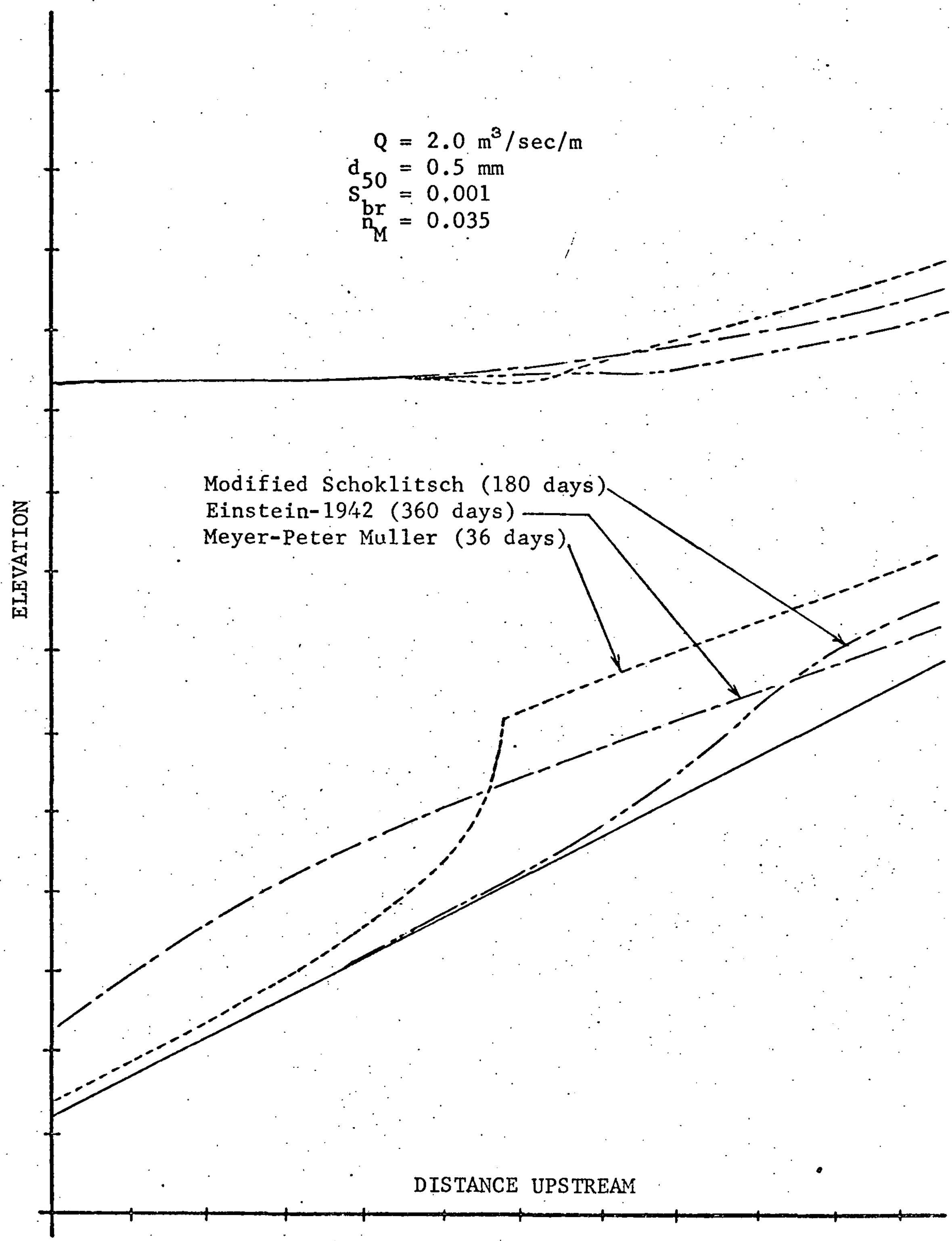

Fig. 9 Comparison of Three Bed Load Equations

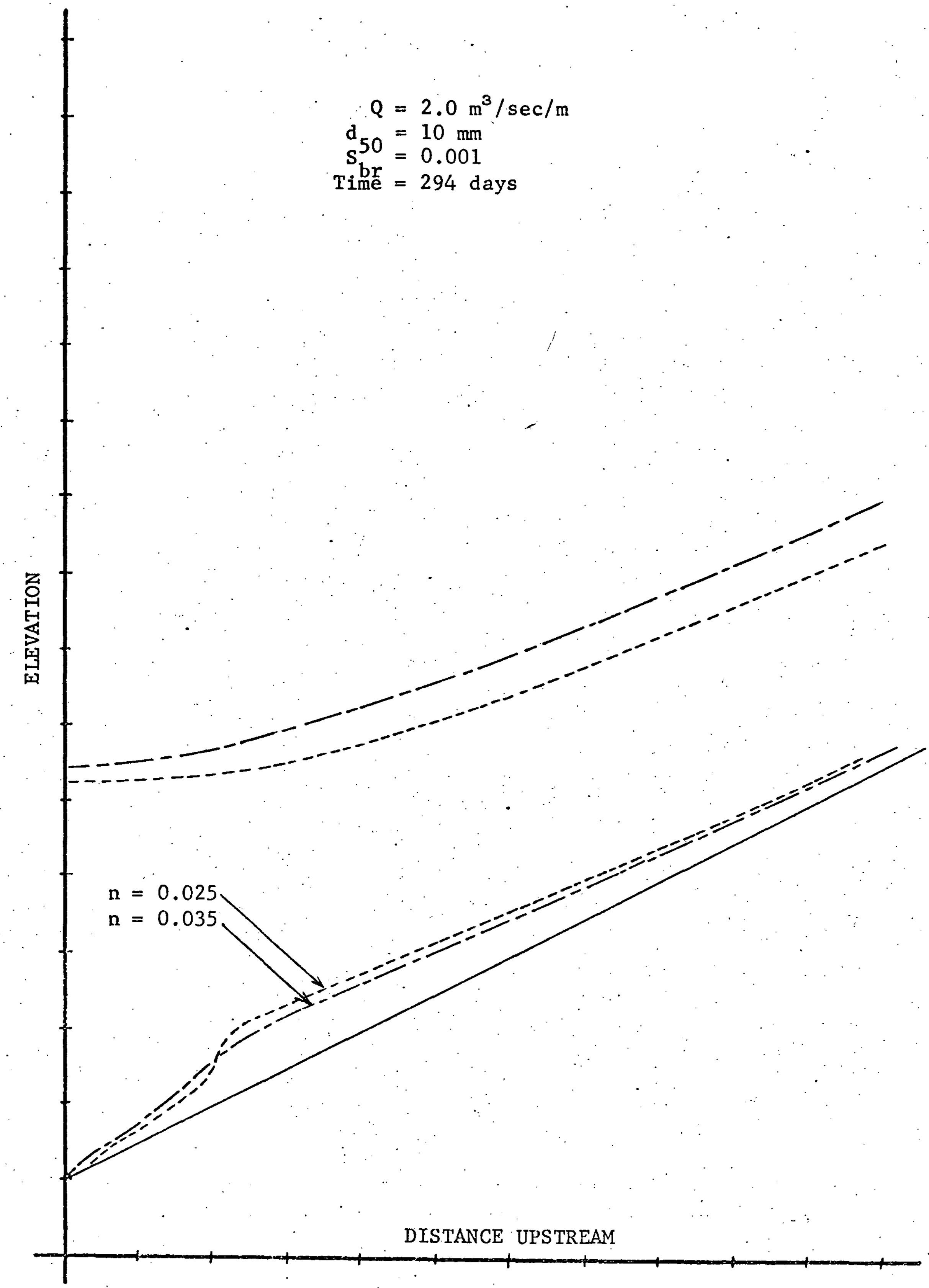

Fig. 10 Effect of Manning, Modified Schoklitsch Equation

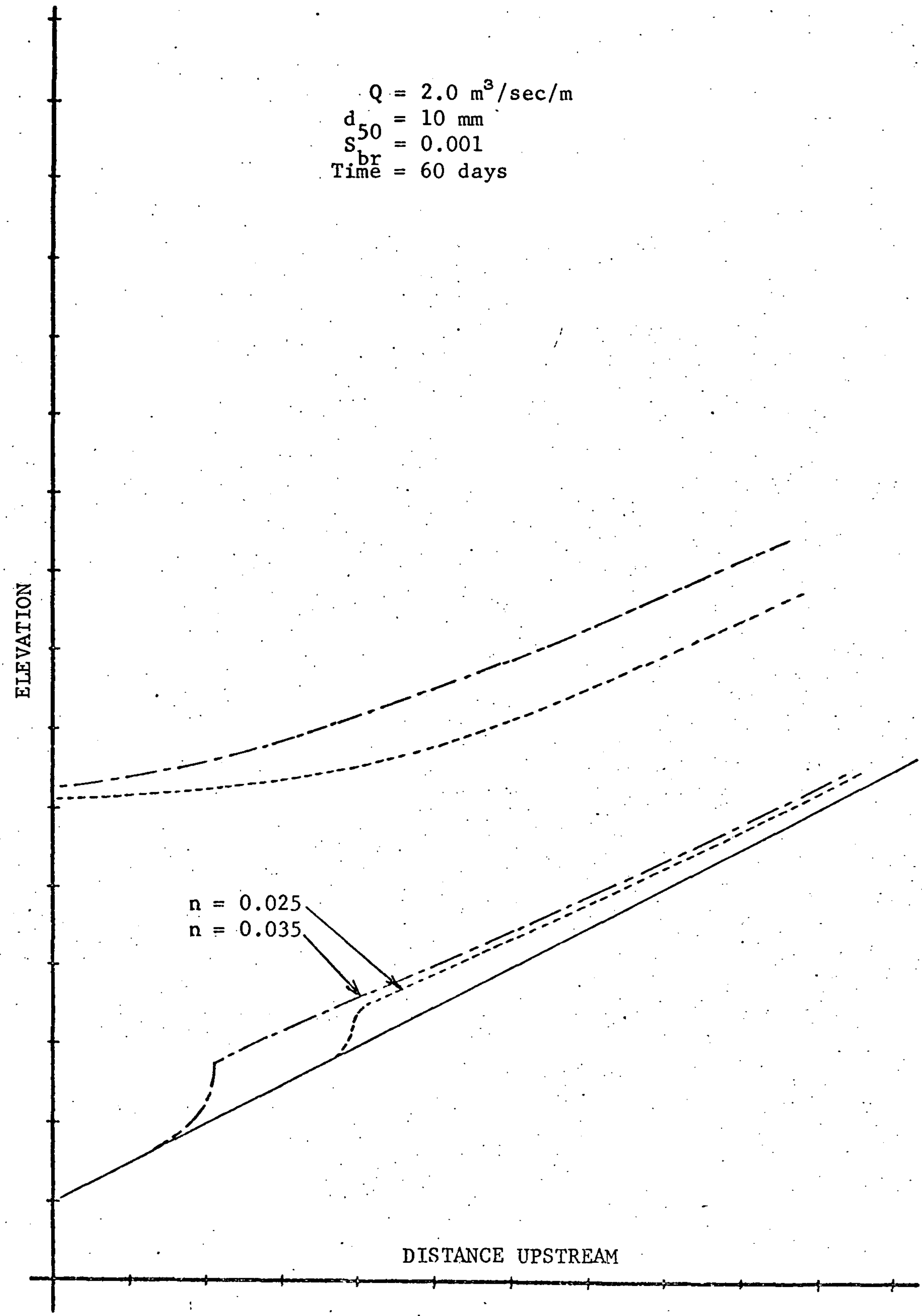

Fig. 11 Effect of Manning n, Einstein-1942 Equation

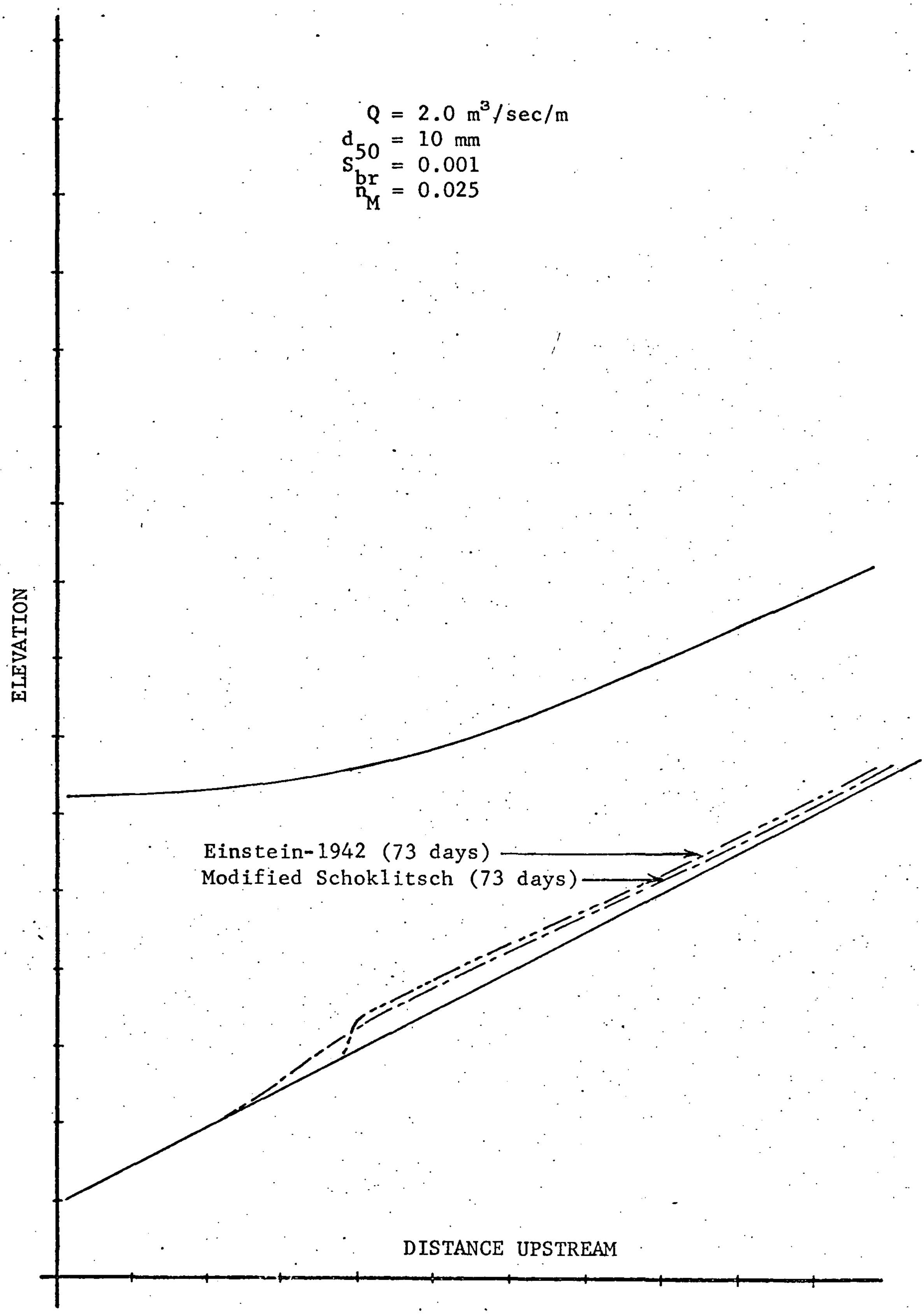

Fig. 12 Comparison of Two Bed Load Equations for Large d_{50}

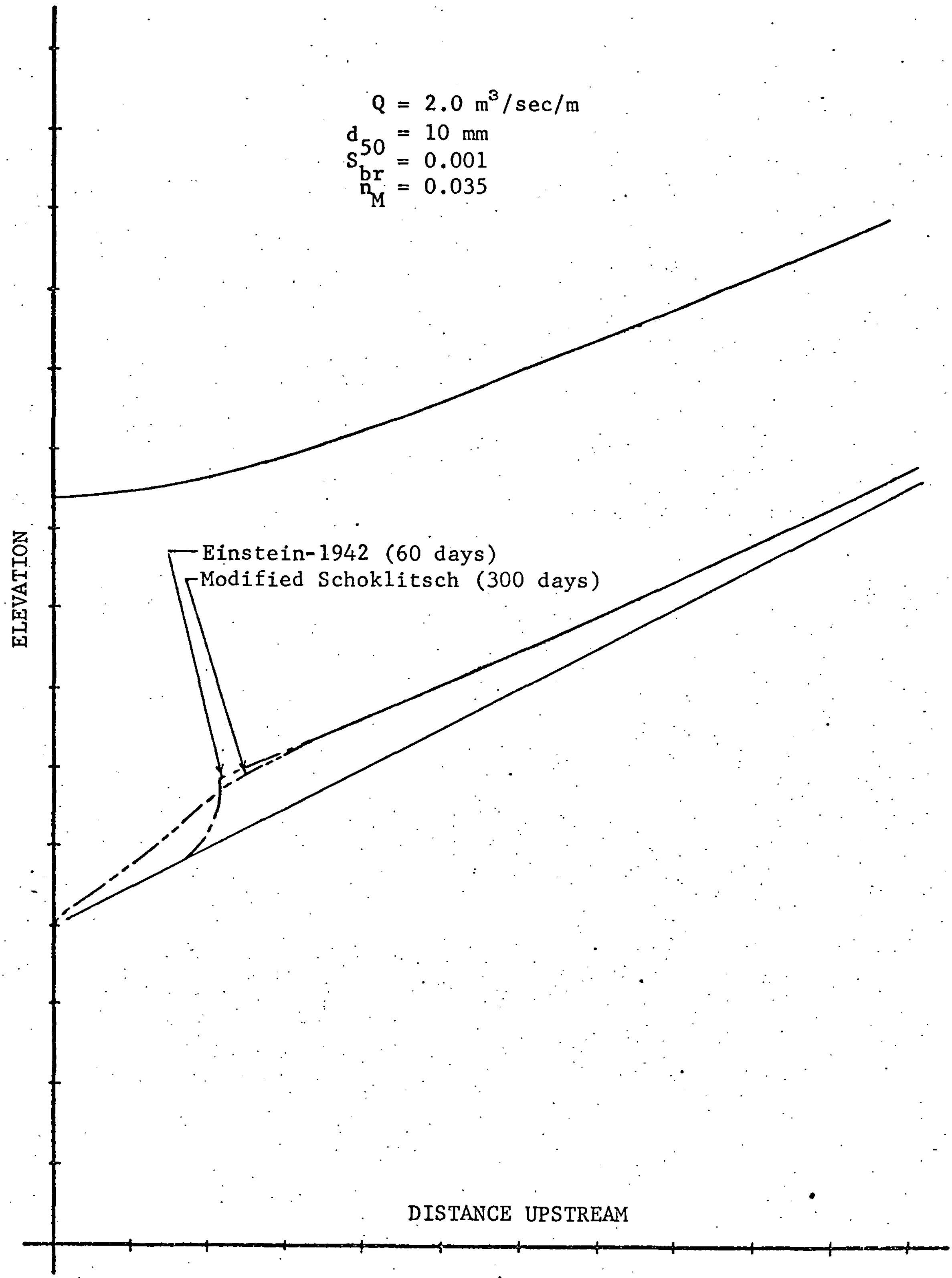

Fig. 13 Comparison of Two Bed Load Equations for Large d_{50}

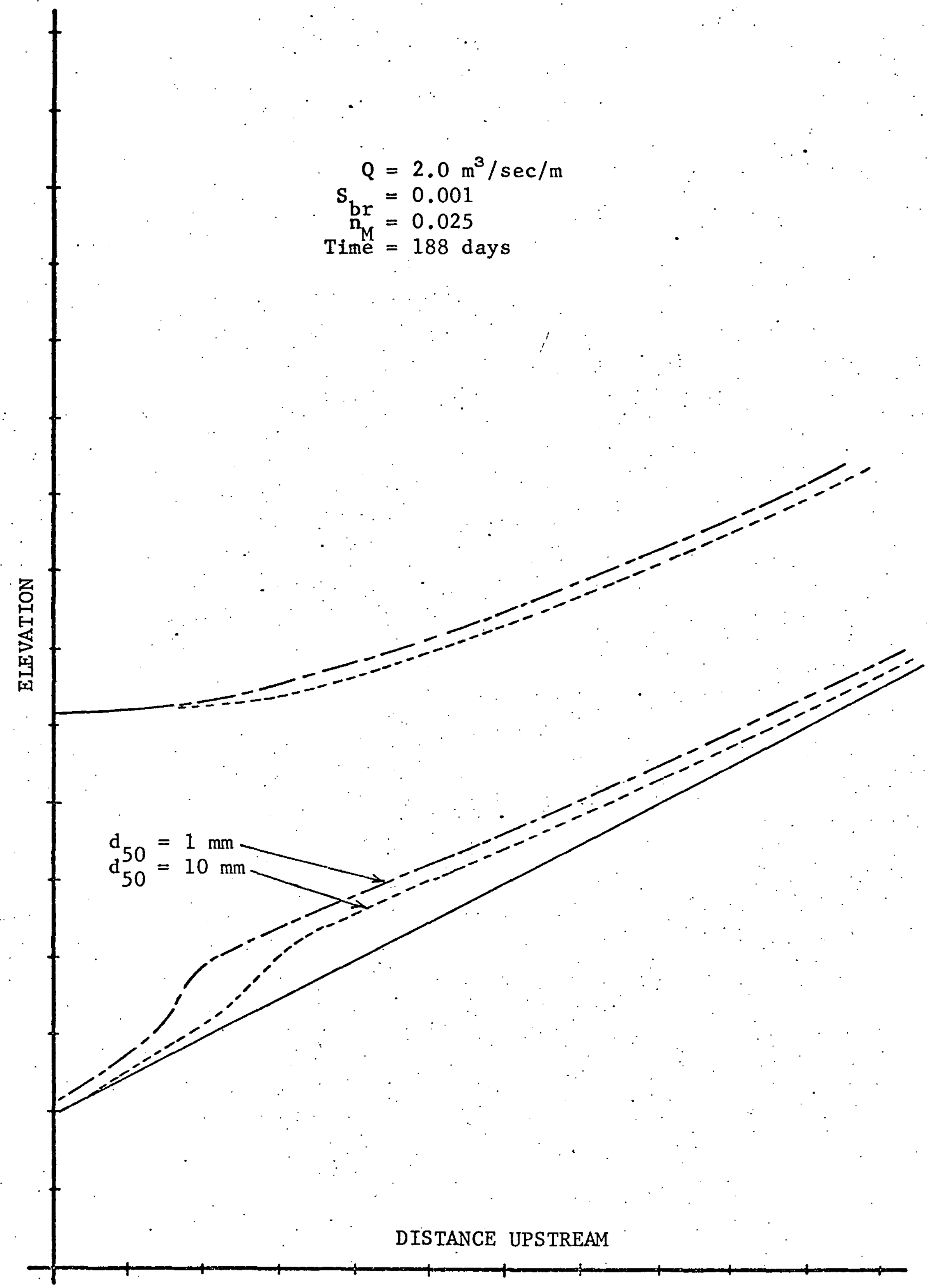

Fig. 14 Effect of Sediment Size, Modified Schoklitsch Equation

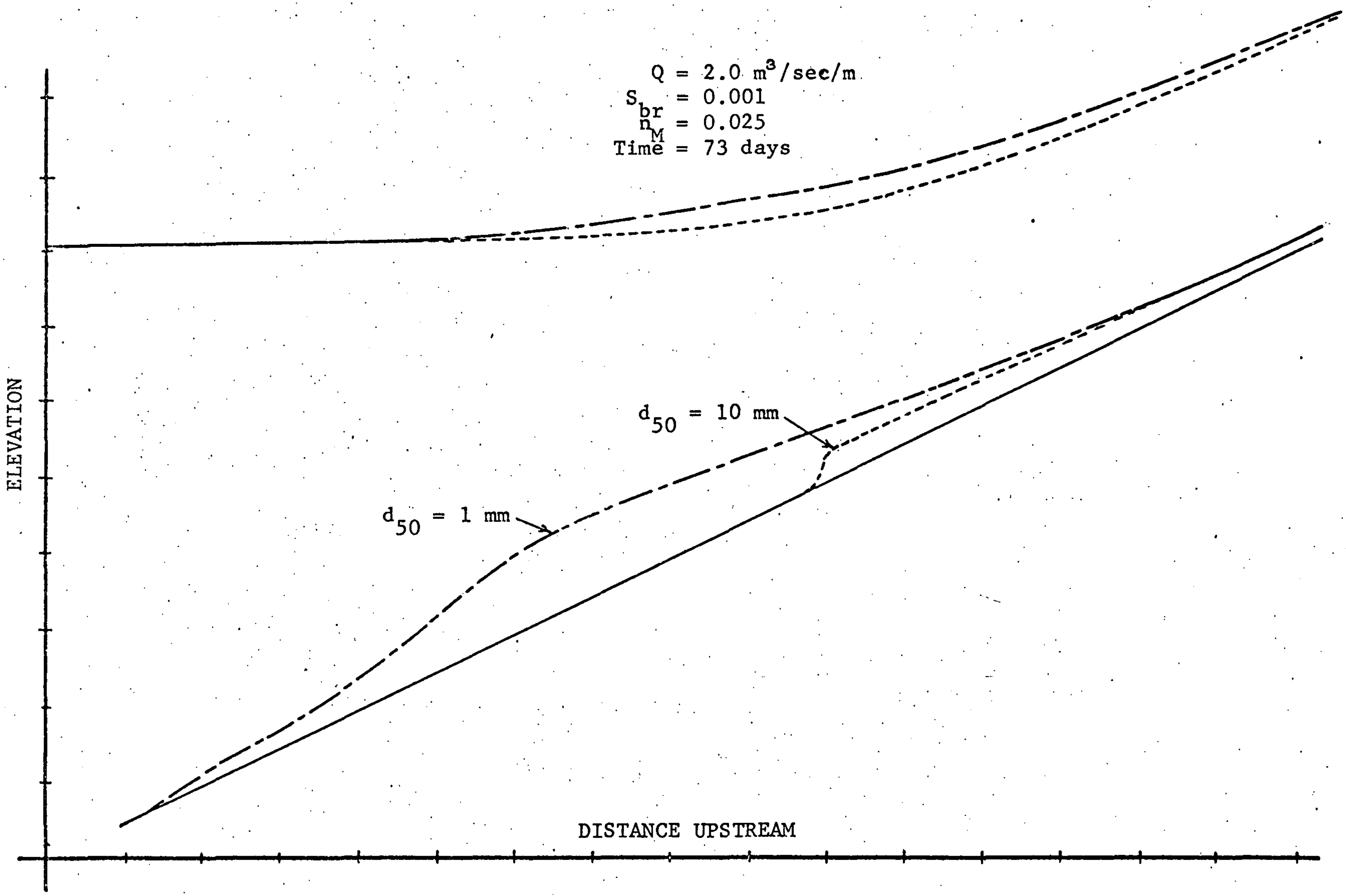

Fig. 15 Effect of Sediment Size, Einstein-1942 Equation